INTRODUCTION

We propose a REE-net project to coordinate networking on the distribution and abundance, impacts, and management of exotic and invasive species in the genus *Bromus* (Poaceae). *Bromus* species include some of the most damaging exotics in the arid and semiarid ecosystems of the western US. These species are tightly linked to fire frequency and size, watershed stability, native biodiversity, and ultimately the conversion of diverse perennial communities into annual grasslands that have reduced agronomic and ecological value (Knapp 1996, Brooks and Pyke 2001). Our project will foster communication among the many *Bromus* specialists in the western US, ultimately leading to ideas for transformative research and extension on understanding and controlling exotic *Bromus* in semiarid rangelands.

Project purpose: resistance and resilience to Bromus *species*

The *Bromus* REEnet project will be unified by a theme of resistance (i.e. the ability to remain uninvaded) and resilience (i.e. the ability to return to a previous state after invasion) of agroecosystems to exotic and invasive *Bromus* species. Its objectives, stated tentatively to allow flexibility, are:

- Collate and synthesize existing distributional, ecological, biological, and management information on invasive *Bromus* species in the western US. Topics such as ecological amplitudes, genetic variability, history of invasion, succession, interactions with ecosystem services, effects of livestock grazing, and effectiveness of control and management techniques will be addressed.
- Compare and contrast these variables among species and regions, identify data gaps and assumptions requiring testing, and address transferability of information and management recommendations among species and regions.
- Assess potential responses of *Bromus* to climate change with the overarching question of how changes in resistance and resilience of native communities and changes in the invasiveness of *Bromus* will lead to changes in ecological impacts, distribution, and control of *Bromus*.
- Extend findings to scientific and management communities through publications and meetings to advance understanding of processes and mechanisms underlying observed patterns, and to inform management decisions and priorities

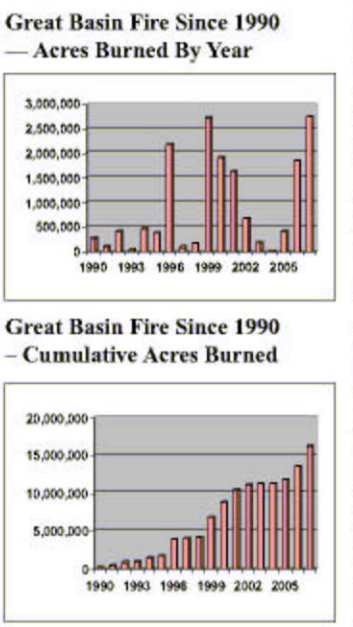

Figure 1. Fire occurrence from 1990 to September, 2007, in the Great Basin (McKnight, 2008)

Background

Bromus species originating in Eurasia have met seemingly little resistance or resilience to their ongoing invasion of the western US. Over the past 150 years, *Bromus tectorum* (cheatgrass) has dispersed from its Eurasian sources to much of the semiarid rangelands of western N America,

primarily in the cold desert of the Great Basin, and more recently in basins of the Southern Rocky Mountain ecoregion (Mack 1981). *B. tectorum* covered a minimum of 2 million hectares or 5% of the Great Basin in the 1990s (Bradley and Mustard 2005), and an additional 15 million hectares are estimated to be at high risk of invasion within the next 30 years (Suring et al. 2005). The resulting losses in big sagebrush (*Artemisia tridentata*) habitat are extensive, and it is now the most rapidly disappearing habitat in the US (Chambers and Wisdom 2008). Domestic livestock production can decrease substantially with *B. tectorum* invasion, which often might increase early season forage at the steep and hard-to-quantify expense of less forage at mid- and late summer as native perennials are excluded from sites. Furthermore, the conversion of sagebrush steppe to annual grassland is contributing to the decline of the greater sagegrouse, and the pending listing of this species as threatened and endangered will shift jurisdiction of the vast rangelands in the Great Basin towards conservation and further from agricultural purposes. *B. rubens* (syn: *madritensis;* red brome) has begun expansion into the rangelands of the warm desert such as the Mojave in recent decades, and the pattern and impacts of invasion appear to parallel that of *B. tectorum* (Brooks and Matchet 2003, Brooks et al 2004). At higher elevations and more mesic habitats, exotic species like *B. diandrus* (ripgut brome) in California and *B. inermis* (smooth brome) pose increasing problems for native plant diversity.

Bromus tectorum and *B. rubens* are archetypal exotic annual grasses, which tend to be distinguished from native herbs in their early season and vigorous growth patterns, production of fine and highly combustible fuels, and proliferation following wildfire. Native perennials are selectively excluded by direct competition with these exotics and the increased fire occurrence they cause. Large wildfires have accompanied *B. rubens* in the Mojave Desert, and fire frequency and sizes have greatly increased in the Great Basin as *B. tectorum* has invaded (Chambers and Wisdom 2008). The western US experienced a greater duration of multi-year drought in the last decade than in recent millennia, as indicated by Palmer Drought Severity indices derived from dendrochronology (Debinski et al, in review). The western US is also predicted to experience greater changes in climate compared to other regions (IPCC assessment overview in Bradley 2009, Figure 1).

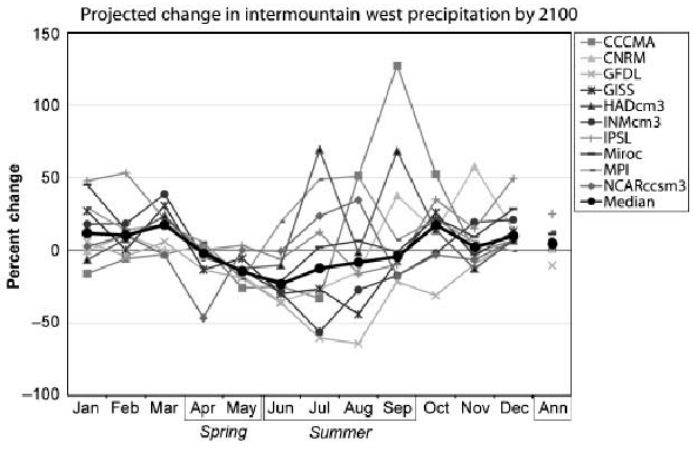

Figure 1: Summary of GCM model predictions in the IPCC 2007 report, used for Table 1, From Bradley 2009

Table 1 Change in suitable land area for cheatgrass for a range of 2100 climate projections

Climate variable	Change scenario	Suitable land area (km^2)	% Change
Current conditions	None	760 000	0
Summer precipitation	Max decrease	1 100 000*	+45
	Median change	860 000	+13
	Max increase	230 000†	70
Annual precipitation	Max decrease	770 000	+1
	Median change	750 000	1
	Max increase	660 000	13
Spring precipitation	Max decrease	590 000	22
	Median change	710 000	7
	Max increase	720 000	5
Winter temperature	2° increase	690 000	9
	4° increase	480 000†	37
Summer, annual, and spring precipitation	Median change	780 000‡	+3

Altered precipitation and warming are linked to increases in wildfire occurrence (Westerling et al. 2006). How the direct effects of climate will combine with shifts in fire activity to alter community resistance to *Bromus* and ability to recover from invasion are major

questions. Recent bioclimatic envelope modeling (BEM) efforts suggest increases for *B. tectorum* (Bradley 2009; Table 1). BEMs provide a spatially explicit assessment of current invasion risk, and can be used to project how invasion risk is likely to shift with climate change. Uncertainty in climate projections and in spatial information is partially overcome by combining results of many models into an "ensemble" projection.

In the case of *Bromus inermis* (smooth brome, native range is France to Siberia) and other exotic and invasive *Bromus* species that are regularly planted in restoration and reclamation, introduction is intentional and impacts of escaped grasses have received less attention. Rocky Mountain and Teton National Parks are two sites that have increasing abundances of smooth brome, which is still regularly planted as dryland farms are put into the USDA Conservation Reserve Program or are subdivided into recreational residences (Parmenter et al. 2003; Debinski et al. in review). Smooth brome forms dense sod that appears to exclude native species yet is vulnerable to invasion by knapweeds or other secondary invaders (Hill et al. 2006). High elevations of the intermountain west are thought to be particularly vulnerable to warming, and whether areas reseeded or invaded by smooth brome will leave a floristic "vacuum" and become prone to the advance of *B. tectorum* under warmer and drier conditions is a major question. Furthermore, combustability of dense *B. inermis* swards, which are prevalent in the productive highlands of the intermountain west, is an increasing issue with recent warming and drought trends.

Information gaps

Despite the abundance of research that has been conducted on exotic *Bromus* species in the western US, much more remains to be learned and communication of what is known must be improved to enable optimization of management across the region. There are basic data gaps in the current and potential future distributions of *Bromus* species, and more fundamental shortcomings in basic understanding of *Bromus*. Some bioclimatic envelope modeling for *B. tectorum* has been accomplished based on remotely sensed information (Bradley 2009), but there are nevertheless limitations in our understanding of the climate envelope of *Bromus* species – particularly in their capacity to adapt to environmental change. While *B. tectorum* and other *Bromus* species typically self pollinate, several new reports of heterozygosity demonstrate the potential for adaptation (Ashley and Longland 2007**,** Kao et al. 2008). As climate changes allow for biogeographic movements of *Bromus* species, questions like whether they will coexist, replace one another, or hybridize and enable new climate and ecological responses are important information gaps.

How existing populations of one *Bromus* species will create or inhibit vectors for the spread of other *Bromus* species is a particularly intriguing and relevant question for management of existing infestations. A common pattern among *Bromus* invasions is that they are followed by invasion of other species, such as knapweeds or skeletonweed, and appear to lead to metastable exotic communities (Kulmatiski, 2006) – yet there has been no synthesis of these succession processes. Succession is a major consideration for biocontrol prospects, considering the vast monocultures formed by several *Bromus* species and the problem of revegetation (or reinvasion by other exotics) following mass eradication events. Questions lie in understanding the degree to which soil feedback mechanisms might reinforce *Bromus* presence and thereby retard restoration efforts (e.g. Rowe et al. 2007, Rowe and Brown 2008, Rowe et al. 2008). Furthermore, climate change is likely to generate novel temporal patterns of temperature and moisture for any given site (Williams and Jackson 2007, Bradley et al. 2009), and concise consideration of how shifting

windows of snow, rain, and growing temperatures will impact *Bromus* species have not been made (Smith et al. 1997). Direct effects of increased CO_2 selectively benefited *B. rubens* in invaded warm desert in a CO_2 enrichment study (Smith et al. 2000), and how these direct effects will contribute to changes in *Bromus* species distributions and impacts need further consideration. Comparing and contrasting *Bromus* species invasion and impacts in the various desert types has not been formally attempted for rangeland in the western US.

Research and extension efforts for *Bromus* control have tended to evaluate eradication methods, and other than the well-known fire-*Bromus* relationship (Mack 1981), there is a critical gap in our knowledge of the resistance and resilience of different plant communities to these exotics. *Bromus* communities appear to be highly resistant to restoration efforts, which contributed to the widespread adoption of state-and-transition models (Laycock 1991) that recognize the potential for restoration of difference states of plant community degradation or development. However, the resistance and resilience of native rangeland communities to *Bromus* must be understood for current and shifting climate scenarios (e.g. Beckstead and Augspurger 2004, Prevey et al. accepted, Chambers et al. 2007) in order to promote effective control and restoration. Studies evaluating the long-term persistence and stability of *Bromus* communities are relatively rare, although the vulnerability of *Bromus*-invaded sites to exotic forbs (eg. *Centaurea*, thistles) and development of quasi-stable exotic communities has been indicated in several studies (Hill et al. 2006, Kulmatiski 2006a, Kulmatiski et al. 2006b).

More practically, how native plant augmentation, grazing, fire, or other control measures can be effectively used for *Bromus* have not been synthesized with respect to both current and future climates. Other prospects for *Bromus* control requiring development include motivation of land owners (Brunson and Tanaka, in prep). Whether cultural and native plant considerations can improve control is a major question. Effective biocontrol agents have yet to be identified, but there are some prospects for microbial agents (e.g. soil-suppressive bacteria; Kennedy et at. 1991 and fungal seed pathogen; Beckstead et al. 2006). Collateral damage in side effects of control measures (e.g. Sheley and Denny 2006) or long-term effectiveness of control measures (Rinella et al. 2009) are considerations requiring further study. Herbicides are commonly applied by BLM and others to areas as large as 20 K ha via plane drops (eg. 2009 Minidoka fires, Idaho), raising concern and risks of multi-million dollar litigation on long-distance transport and collateral issues (e.g. alleged crop losses in a region of potato farms in SE Idaho following sulfometuron (Oust) application in S Idaho). Notably, as *Bromus* invasion into sagebrush steppe has occurred, its interaction with post-fire wind erosion is a novel concern related to hydroclimatological changes (Sankey et al. 2009a,b).

Programs linked to the proposed **Bromus** *REE-net Project*

The *Bromus* REEnet will formally incorporate an array of research and extension groups in western N America that are otherwise not well integrated despite some overlap in personnel, including eight major programs listed below. One existing group, the GBRMP (described below) will provide direct and reciprocal benefits to the *Bromus* REEnet. Several of the constituent groups described below have considerable experience in research and extension, plus direct links to land owners and managers, to offer the *Bromus* REEnet. In return, the *Bromus* REEnet offers a formal and efficient platform for the groups to compare approaches and findings. Where redundancy in approaches has occurred, *Bromus* REEnet will enable the groups to determine what can be learned from it. For example, perhaps comparing and contrasting efforts will reveal that a management tool works under one location and condition but not in

other situations, or perhaps the redundancy provides reinforcement of the general effectiveness of a *Bromus* management approach. Also, specific findings and outcomes from these projects have been slow to materialize, and the *Bromus* REEnet symposia presentations and proceeding will promote collated reporting of outcomes. Most importantly, the intent of *Bromus* REEnet is to foster interactions that improve integration of current and future *Bromus* projects.

1) GBRMP: host of the Bromus REEnet

Overview and composition- *Bromus* REE-net will be a working group in the Great Basin Research and Management Partnership (GBRMP, www.greatbasin.wr.usgs.gov/GBRMP), which will provide an existing interdisciplinary and institutional host for *Bromus* REEnet, in addition to an extension aspect and an established web host for the database. In turn, *Bromus* REEnet is likely to have formative influences on subsequent GBRMP activities and directions. The GBRMP consists of a large group of agencies and universities, including *Bromus* REEnet participants Jeanne Chambers and Stuart Hardegree, who are founding co-chairs of the GBRMP coordinating committee, James MacMahon and Michael Auerbach of the executive committee, and coordinating-committee members Angela Evenden and Matt Germino. The concept and initiation of this *Bromus* REEnet proposal was an outcome of regular GBRMP meetings, and the GBRMP has voted to endorse and support the project as it applies to the Great Basin and surrounding rangeland of the western US.

Objectives- The GBRMP transcends the missions of any of its constituent partners in coordinating pro-active assessment and consensus for prioritizing research and management needs. This is in contrast, agencies that are generally constrained to existing, established problems (e.g., reactive remediation). The objective of the GBRMP is to coordinate interdisciplinary, multi-organizational, research and management teams to develop solutions to ecological and socio-economic problems in the Great Basin. An emphasis is placed on promoting comprehensive and complementary research and management collaborations to sustain ecosystems, resources and communities across the Great Basin. A tangible outcome of GBRMP activities will be recommendations to land managers. The specific goals of the GBRMP, which are closely aligned with the stated intent of the AFRI REEnet opportunity, are to:

1. Maximize integration of science and management through partnerships and technology transfer.
2. Provide leadership and commitment to an integrated organizational framework linking science and management to address priority natural-resource and socio-economic issues in the Great Basin.
3. Expand and facilitate inter-disciplinary, multi-organizational teams focused on problem solving through collaborative management and research.
4. Identify opportunities to leverage limited resources, minimize duplication, and pursue additional support and resources toward shared goals.
5. Implement communication and information sharing that enhances problem solving, demonstrates measurable results, and increases public support for Great Basin sustainability.
6. Produce measurable and meaningful outcomes in support of its mission and goals.

Status- The need for the GBRMP was identified during a 2006 open conference that focused on collaborative research and management in the Great Basin (Chambers et al. 2008, Chambers and Wisdom 2008). GBRMP has met about monthly since then, and has been formal endorsed by an MOU and financial support from the participating universities and agencies.

2. JFSP SageSTEP

Overview and composition- SageSTEP (sagebrush steppe treatment evaluation project; http://www.sagestep.org) is comprised of a large group of university and agency research and extension specialist from Utah, Nevada, Idaho and Oregon who are conducting broadly replicated experiments on land management tools for restoring sagebrush communities in the Great Basin. SageSTEP is funded by the Joint Fire Science Program (JFSP). *Bromus* REEnet participants who are members of the SageSTEP research and extension effort include Jeanne Chambers, David Pyke, Mark Brunson, and Eugene Schupp.

Objectives- SageSTEP experiments are examining the ecological thresholds that determine the recovery potential of sagebrush communities following select management treatments over a broad range of environmental conditions across the Great Basin, in Idaho, Oregon, Washington, Nevada, and Utah. One of the two SageSTEP experiments is focused on *B. tectorum* invasion, and is aimed at determining the site characteristics (e.g., soil characteristics, abundance of native perennial herbaceous species, water availability) necessary for management treatments to improve ecological conditions. The management treatments are tested over gradients of *B. tectorum* invasion in order to define the ecological thresholds., Prescribed fire and thinning of sagebrush by both mowing and herbicide applications are used to decrease the amount of sagebrush in the system and increase resource availability for perennial herbaceous species. A pre-emergent herbicide specific to annual species is used to decrease the abundance of *B. tectorum* and give the perennial herbaceous species an additional advantage. Treatment effects on fuel loads, soils, water runoff and erosion, and birds and insects are being documented. Also, an economic analysis is being conducted to assist managers in selecting optimal management strategies, and citizens' and managers' views about the treatments are being explored.

Status- The SageSTEP has implemented nearly all planned field experiments in its first years, and there are two years of funding remaining and considerations of future directions are recently beginning. SageSTEP, which has a strong extension component and has produced guides for fuels management, an outreach DVD entitled "Restoring Sagebrush Rangelands: An Introduction to Alternative Land Management Strategies", a widely distributed electronic periodical entitled "SageSTEP news" that appears three times per year, Regular meetings and other highly visible outreach activities that involve land managers and other stakeholders are held.

3. USDA ARS Ecologically Based IPM

Overview and composition- The Ecologically Based Integrative Plant Management program (EBIPM; http://ebipm.org) of the USDA Agricultural Research Service is an extension project that works closely with land owners to employ ecological and specifically successional strategies towards controlling annual grasses such as *B. tectorum*. The EBIPM effort draws from ARS stations at several locations in the Great Basin, and includes *Bromus* REEnet participants Thomas Monaco, Stuart Hardegree, Roger Sheley, and Jeremy James.

Objectives- The EBIPM program seeks to enable future weed management to be based on an understanding of the biology and ecology of rangeland ecosystems and particularly plant community processes, such that treatments address causes of invasion rather than on just eradication of exotics. Thus, a central goal is to test methods for restoring diverse plant communities that function in maintaining ecological processes by modifying the processes and mechanisms directing plant community dynamics and structure. EBIPM combines state and transition models and successional management models to make the best decisions for a given

areas. The EBIPM model was developed based on the three general causes of succession: site and species availability and species performance. For example, in order for succession to occur, a niche must be available for desired species and unavailable for undesirable ones. Once a site is available, desired species must establish before exotics. Processes that are incorporated into management tools include seed dispersal, and vegetative reproduction. When sites for desired species are created and they become established, factors that favor the desired species must be considered, such as grazing, disease, and resource availability.

Status- The EBIPM program provides funding for 2008-2012, and is projected to continue indefinitely as cooperators continue to augment the effort with external funding sources such as those culminating from *Bromus* REEnet activities.

4. BLM Great Basin Restoration Initiative

Overview and composition- the BLM Great Basin Restoration Initiative (GBRI, www.blm.gov/nifc/st/en/prog/fire/more/gbri/information.html) was formed to promote restoration of sagebrush steppe degraded by *B. tectorum* invasion and related problems. It is funded by congressional appropriation and executive order, and is coordinated by *Bromus* REEnet member Michael Pellant. The program was formed to promote a more comprehensive restoration program to supplement emergency fire rehabilitation, which occurs immediately following a fire to stabilizing soils and thus is less apt to meet long-term restoration goals. The rationale was that fire suppression or fuels reductions and weed control were not adequate or were too slow to control the spread of exotic plants. An interagency, interdisciplinary team has been established to work with the public in developing 1) steps required to identify and inventory plant communities needing protection or restoration, 2) partnerships necessary to obtain critical research and increase seed production, 3) monitoring strategy, and determine how priorities for restoration will be decided.

Objectives- The long-term restoration program goal of the BGRI is to develop diverse and resilient plant communities to help restore the health and productivity of BLM Great Basin rangelands by allowing the agency to gradually return lands dominated by annual exotic grasses to its native character. An estimated 500,000 acres is targeted for treatment annually using private contractors. To facilitate habitat restoration, treatments vary from mechanical to chemical and include seedings, plantings, fence, and water developments. Restoration efforts are done in conjunction with emergency fire rehabilitation. Efforts protect areas with high-resource values from noxious weed and exotic annual grass invasions, and restore crucial areas and native shrublands degraded by invasive species. Restoration priorities are set based on inventories and assessments; public involvement; proximity to adjacent landowners; level of community support; places where wildlife habitat, especially threatened and endangered species, are a concern; and wildland-urban interface. Several projects are important components of the GBRI, including:

The Great Basin Selection and Increase Project: A multi-state, collaborative research project was initiated in 2001 to evaluate, select, and increase native seed production in the Great Basin under the leadership of the USFS Intermountain Research Station (Nancy Shaw). To improve the availability of seed from 49 native species in the project, especially forbs, for restoration projects and rehabilitation after wildfires, the following steps are taken: 1) collection of native seed, 2) evaluation and selection of plant material for restoration, 3) seed production by private sector, and 4) application of native plant restoration. *Bromus* REEnet participant Thomas

Monaco also is a participant in the Selection and Increase project, and has evaluated functional similarities of restoration plants with *B. tectorum*.

Coordinated Intermountain Restoration Project (CIRP): CIRP is a cooperative research project under the leadership of the United States Geological Survey in conjunction with the Bureau of Land Management. CIRP is led by *Bromus* REEnet participant David Pyke. The objective of this project is to increase understanding of natural and human-caused disturbances (e.g., wildfires, livestock and recreational impacts, etc.) and of invasive plants in the Intermountain West, while developing strategies to manage, maintain, and restore above- and below-ground biodiversity and functional ecosystems. CIRP goals are to 1) develop techniques to maintain or restore functioning ecosystems, 2) understanding ecological responses to disturbance and invasive plants, and 3) demonstrate and transfer scientific results and applications

Status- The GBRI was initiated in 1999 following extensive wildfire in *B. tectorum* – invaded sagebrush steppe, and the program does not have a termination date.

5. Rocky Mountain Cheatgrass Management Project

Overview and composition- This project is lead by *Bromus* REEnet co-PI Cynthia Brown, and additionally includes Maria Fernandez-Gimenez and Marshall Frasier who specialize in sociological and economic aspects of natural resources and rangelands. The project is currently funded by an Integrated award from USDA NRI, the Western Integrated Pest Management Center, and the Agricultural Experiment Station.

Objectives- The project goal is to develop integrated ecological and economic decision support tools that enable land managers, producers and extension specialists to (1) assess the condition of their rangeland with respect to *Bromus tectorum* invasion and its effects, (2) evaluate management inputs necessary to improve the condition of the land, (3) weigh the costs and benefits of the options under uncertain environmental conditions, and, (4) improve the ecological state of the land and economic status of the rancher. These questions were driven by communication with members of the Southeast Wyoming Cheatgrass Partnership, a group of public and private land managers and extension specialists from Colorado and Wyoming.

A three tiered approach is being taken to accomplish objectives:

1. Field experimentation to test effects of integrated pest management practices on *Bromus* and ecosystem processes.
2. Integration of a process-based ecosystem simulation model with a production driven economic model to test management strategies and implications at larger spatial scales and under different environmental conditions.
3. Development of a website, management handbook, workshops and field tours targeting three stakeholder groups: extension specialists, land managers, and producers. Focus groups to help develop extension activities and materials, and steer future work will be formed from the stakeholder groups. Success in meeting the project objectives and the overall impact of extension and research activities will be measured with surveys to assess stakeholder knowledge before and after the project, and practicality and usefulness of extension tools.

Status- USDA NRI funding for the this project began last fall and continues for 4 years.

6. NSF Global Invasion Network

Overview and composition- The NSF funded Global Invasion Network Research Coordination Network is a group of 50 scientists from around the world, which includes *Bromus* REEnet Co-PI Cynthia Brown, and Steven Novak and Kristina Schierenbeck. The group is working to integrate the diversity of hypotheses of biological invasions and coordinate empirical and theoretical research on the ecology and evolution of invasive species.

Objectives- The Network will develop a predictive framework that integrates the many hypotheses regarding controls on biological invasions, facilitate identification of and collaboration among scientists with complementary interests, and promote collaboration and coordination of research on the ecology and evolution of invasive species.

Status- The Network has held Network meetings in Colorado and Prague, Czech Republic, and sponsored research exchanges, workshops, and symposia. This effort will continue through 2011.

7. NSF NEON

Overview and composition- The National Environmental Observation Network Inc. (NEON; www.neon.org) is an NSF-funded effort to establish continental scale monitoring and large-scale ecological experiments. The science to be addressed by NEON links theories from physics, ecology, genetics, and ecosystem science. NEON consists of a large contingent of staff and stakeholders, and *Bromus* REEnet participant James McMahon was a central leader in the development of the program. Other *Bromus* REEnet participants are actively involved in the development of NEON core sites, such as Matt Germino (Northern Rockies, NORMEO) and Jeanne Chambers and Richard Mack (Great Basin, IRON).

Objectives- Two questions are considered the "grand challenges" for NEON:

- How will ecosystems and their components respond to changes in natural- and human-induced forcings such as climate, land use, and invasive species across a range of spatial and temporal scales? And, what is the pace and pattern of the responses?
- How do the internal responses and feedbacks of biogeochemistry, biodiversity, hydroecology and biotic structure and function interact with changes in climate, land use, and invasive species? And, how do these feedbacks vary with ecological context and spatial and temporal scales?

NEON will link diverse technologies for environmental and biotic measurement in the following:

1. Twenty heavily instrumented core sites, located in wildland areas selected to span the range of major US climate zones and ecosystems. The Great Basin core site is at the Onaqui-Benmore Experiment Station, also a SageSTEP experimental site.
2. Airborne observatory platforms with remote sensing instruments to provide regional information for scaling and extrapolation from sites.
3. Gradient sites, serviced by mobile or relocatable systems (including the TNC Dugout Ranch, which has *Bromus*), located to facilitate understanding through observations of ecosystems exposed to long-term differences in key environmental or human-dimension factors, such as elevation, precipitation, land use, time since disturbance, and location within a major watershed.

Status- NEON has been nearly a decade from conception to implementation. The current stage of development is establishment of the core administrative offices in Boulder CO and initial test

sites. Study sites have been selected and organization is underway.

8. Great Basin CESU

Overview and composition- As for each region of the US, most of the universities and land agencies in the Great Basin are participants in a Cooperative Ecosystems Studies Unit (CESU) that is designed to facilitate technology and expertise transfer from universities to federal land needs. Members of the *Bromus* REEnet who also participate in the Great Basin CESU include Jeanne Chambers, Eugene Schupp, and Matt Germino.

Objectives- The CESU objectives are to 1) provide research, technical assistance and education to federal land management, environmental and research agencies and their potential partners, 2) develop a program of research, technical assistance and education that involves the biological, physical, social, and cultural sciences needed to address resources issues and interdisciplinary problem-solving at multiple scales and in an ecosystem context at the local, regional, and national level; and, 3) place special emphasis on the working collaboration among federal agencies and universities and their related partner institutions.

Status- The Great Basin CESU agreement was authorized in 2006, and the program is expected to continue indefinitely. The volume of contracts between federal land agencies and constituent universities is on the order of millions, annually. The GBCESU meets annually in person and has periodic phone conferences, and has been a constituent in the promotion of new and integrative initiatives in the Great Basin, especially those dealing with invasives and rangeland health.

RATIONALE AND SIGNIFICANCE

AFRI Biology of Weedy and Invasive Species in Agroecosystems (BWISA) Program priorities: The *Bromus* REEnet project directly addresses the first priority by synthesizing and generating new directions for research and extension on the abundance of weedy and invasive species, and the individual and/or collective impacts of these species on a broad suite of ecosystem services, both market and non-market. *Bromus* REEnet will assess and synthesize ecologically-based, invasive species management programs, which will address the second program priority.

Societal importance of *Bromus* impacts to rangeland: Livestock production, wildlife habitat, and more recently energy extraction are ecosystem services provided by semiarid rangelands of the western US. This region also has the highest rate of human population increase in the US, and land managers are increasingly challenged to maintain or improve the ecological condition of these systems and the services that they provide, while meeting the needs of a growing number of user groups with diverse and often opposing interests. Sustaining the ecosystems, resources and human populations of the West will require strong collaborative partnerships among research and management organizations in the region (Chambers and Wisdom 2008).

The combination of *Bromus* invasion and corresponding fire activity is a primary force in the loss of agronomic and ecological values in western rangelands, reducing livestock and wildlife capacity by 35 to 90% (BLM, 1999). With continued degradation, the likelihood of sagegrouse, pygmy rabbit, or other species being listed as threatened and endangered will force management to emphasize their recovery at the expense of livestock concerns. Economic losses associated with *Bromus* and corresponding fire activity are annual treatment costs ranging from $42 million to $155 million annually (BLM, 1999). Nearly $71 per acre is spent each year in

wildland fire management, $64 per acre in emergency fire rehabilitation, and $70 per acre for weed treatments (BLM, 1999). In the Great Basin alone, 165,000 people spend nearly $145 M annually for deer hunting – another declining resource with *Bromus* and wildfire (BLM, 1999).

How the *Bromus* REEnet approach can contribute to the broader needs: The large-scale changes associated with *Bromus* invasion appear difficult or impossible to halt or mitigate with current knowledge and limited human and financial resources. Holistic approaches, sufficiently funded to address critical research and management issues, are needed to achieve positive changes in ecological conditions and ecosystem functions (Chambers and Wisdom 2008).

- Larger-scale and more comprehensive analyses of these ecosystems and their relationship to *Bromus* are needed, including changes occurring and their future implications, as the basis for research activities and management actions.
- Prioritization of restoration and management activities needs to be based on an understanding of both the causes of the changes and potential for recovery based on the inherent resistance and resilience of ecosystems to current and future disturbance.
- A closer alliance between research and management is needed to promote positive change on the landscape.
- A strong focus on effective collaboration and increased communication among research and management organizations and the region's stakeholders is necessary to gain public and political support for adaptive management and ecosystem sustainability.

APPROACH

Overview of scope

The *Bromus* REEnet will compare patterns of invasion, ecological and agronomic impacts, and management systems among *Bromus* species and regions. The REEnet will analyze both historic and possible future patterns of invasion, effects on native ecosystems and ecosystem services, and management approaches for a suite of exotic *Bromus* species.

Geographic scope- The area of concern for *Bromus* REE-net will span rangeland of the warm deserts of the southwestern US (e.g., *B. rubens* or *madritensis*, red brome, in Mojave desert), cold deserts and steppe at higher latitudes (e.g., *B. tectorum,* cheatgrass, in western US) and more productive rangelands of California (*B. diandrus*, ripgut brome). We also include higher elevations that face substantial land use change, where *B. inermis* (smooth brome) can dominate following escape from fallow cropfield and reclamation seedings. The scale of historic and future problems and the amount of knowledge is greatest for *B. tectorum*, and is increasing for *B. rubens*. Thus, treatment of each species will not be equivalent, with relatively greater emphasis on synthesis of information for *B. tectorum* and *B. rubens* and relatively more identification of information gaps and research needs on other *Bromus* species.

Scope of personnel- The extent of the *Bromus* problem in the western US is large, and accordingly there are many individuals who specialize and have achieved high levels of accomplishment in research and management of these species – many more than could realistically be listed in this proposal. Here, we propose a diverse list of core participants who will either represent or will directly involve the participation of the broader *Bromus* research and management communities. Aside from the eight constituent *Bromus* programs, each participant also one or more other NRI, NSF, DOI, or other research and extension grant projects ongoing. Furthermore, we have structured the *Bromus* REEnet to allow formal input of the broader

Bromus community in internet communications, symposia, and symposia proceedings. Core participants listed in this proposal will foster communication across the *Bromus* community without being directly compensated.

The 26 core participants in the *Bromus* REEnet were carefully selected to represent a wide range of disciplines, existing *Bromus* projects, academic and land management personnel, type and size of institutional affiliation, career stage, geographic location and emphasis, and demographic background. Furthermore, we believe these particular individuals are poised to draw from the much larger community of *Bromus* specialists that could not be listed here as core participants, but whose input is highly desired and critical for success of the *Bromus* REEnet:

Matt Germino	Ecology and physiology, GBRMP and CESU representative, Idaho State University
Jeanne Chambers	Research ecologist, Co-chair of GBRMP, SageSTEP and CESU participant, US Forest Service Rocky Mountain Research Station
Cynthia Brown	Invasive plant and restoration ecology, RM Cheatgrass Project, and NSF Global Invasion Network, Colorado State University, Ft Collins
Sheryl Atkinson	Database specialist and graduate student Colorado State University, Ft Collins
Mike Auerbach	Ecologist, GBRMP member, and director, Desert Research Institute, Reno
Julie Beckstead	Microbial pathogen biocontrol, ecologist, and Associate Professor Gonzaga University, Spokane
Bethany Bradley	Remote sensing, climate-range modeling, and Assistant Professor, Princeton University
Matt Brooks	Ecologist, USGS California, Yosemite
Mark Brunson	Human-environment interactions, Professor, SageSTEP member Utah State University
Carla D'Antonio	Ecologist, Professor, University California, Santa Barbara
Angie Evenden	Ecology and administration, National Park Service, CESU, GBRMP
Maria Fernandez-Gimenez	Range Ecologist and Sociologist, RM Cheatgrass Project, Professor, Colorado State University, Ft Collins
Marshall Frasier	Economics, Colorado State University, RM Cheatgrass Project, Professor, Colorado State University, Ft Collins
Stuart Hardegree	Rangeland ecophysiology, co-chair of GBRMP, and EBIPM member Agricultural Research Service, Boise
Beth Leger	Ecology and restoration, Assistant Professor, University of Nevada, Reno
Richard Mack	Ecologist, Professor, Washington State University, Pullman
Jeremy James	Ecologist, Assistant Professor, EBIPM participant Oregon State University, Corvallis
Jim MacMahon	Ecologist, Professor, a founding member of NEON and GBRMP Utah State University, Logan
Tom Monaco	Rangeland ecology and management, EBIPM member Agricultural Research Service, Utah State University, Logan
Steve Novak	Genetics and Ecology, Professor, NSF Global Invasions Network, Boise State University
Mike Pellant	Great Basin Restoration Initiative Coordinator, GBRMP, SageSTEP, Bureau of Land Management, Boise
David Pyke	Ecologist, SageSTEP, CIRP, US Geological Survey, Corvallis
Kristina Schierenbeck	Genetics and research leader, Exotics and Invasives Research Unit NSF Global Invasions Network, Agricultural Research Service, Reno.
Eugene Schupp	Ecologist, Professor, SageSTEP member, CESU representative

	Utah State University, Logan
Roger Sheley	Ecologist, EBIPM member, Agricultural Research Service, Burns
John Stark	Soil microbiology, biogeochemistry, Professor, Utah State University, Logan

The essential "structural" feature of the *Bromus* REEnet will be subgroups of individuals who develop one or several presentations, manuscripts, and proposals that *synthesize information* and *identify questions* to fill information gaps in either 1) synthesis, prediction and modeling, 2) interdisciplinary and multi-scale experiments, 3) concepts and tools, and 4) communication and technology transfer. Subgroups will be encouraged to identify the extended network of researchers and managers working on *Bromus* related issues. Interactive networking will be promoted by in-person meetings and an internet "chatroom". A database will be developed to structure and facilitate synthesis.

Methods for accomplishing the networking and synthesis

The main tools for promoting interactive networking and synthesis are A) in-person meetings and symposia, B) a website hosting a *Bromus* database and C) internet chatroom, D) incentive and direction in the form of co-authorship on presentations, whitepapers, and proposals, and E) involvement of the extension and management community. Feasibility for accomplishing synthesis and future directions for topics will be increased by having participants interact in groups of manageable size (e.g. several to 7-8 people).

A) Meetings and symposia- The core participants of the *Bromus* REEnet will convene for three meetings that will serve as key opportunities for interaction. In the first meeting, we will introduce participants and their research, management, and extension programs; introduce the database concept; develop subgroups; identify and refine focal questions; and set project goals. In the second meeting, we will present project results in a symposium at WSSA or ESA (Weed Science and Ecological Societies of America, respectively) annual meetings that will include *Bromus* specialists not listed here. Following the symposium, manuscripts will be produced for a symposium proceedings and will be made available by a respected publisher. The third meeting will build on project results and will focus on developing transformative whitepapers and research and extension proposals to agencies like AFRI, NSF, DOE, JFSP, and NEON. Thus, the three meetings will introduce the participants, refine project questions and develop focal groups, present syntheses of major topics and initial results in a symposium, and develop whitepapers and grant proposals. A major outcome will be a vision for where and how future research and extension should proceed.

Below, we list some tentative, plausible foci related to resistance and resilience of western rangeland to *Bromus* invasion and impacts. We anticipate identifying priority knowledge gaps and ways to attain the knowledge. How participants might parse out into subgroups is also suggested below:

1) Synthesis, prediction, and modeling.

- What is the best information on the geographic distribution of *Bromus*, and what are the key patterns of change? (Bradley, Chambers, Brooks, Atkinson)
- How well known are the ecological amplitudes of *Bromus* species, considering both fundamental and realized niches and interactions of climate, disturbance, and plant community type at range margins. (Bradley, Mack)
- How do genetic structures and processes contribute to geographic distributions and ecology of *Bromus*? (Novak, Leger, Mack, Schierenbeck, Brown)

- What ecological factors, such as native diversity, soil biogeochemical feedbacks, ecohydrological patterns, and interactions with insects and animals, affect resistance and resilience of communities to *Bromus*? (Stark, Schupp, Germino, Monaco, James)
- How might economic impacts, attitudes toward management options, and infrastructure for implementing control of *Bromus* change with land use and climate shifts? (Brunson, Fernandez-Gimenez, Frasier, Pellant).
- How do current invasions by one brome species and the accompanying spatial matrix of land use, disturbed ground, roads, and other vectors set the stage for movements of other *Bromus* species under changing climate? (Brooks, Brunson, McMahon)

2) Interdisciplinary and multi-scale experiments combining research and extension

- What are the unique contributions of science and management practice from each of the major *Bromus* programs? (a representative from each program)
- What are the priority questions, approaches, and ideal infrastructures for future, large-scale research and extension projects? (MacMahon, Auerbach, Evenden; all)

3) Concepts and tools

- What is the best current insight on successional relationships of *Bromus* species with both native and exotic species, and how might current *Bromus* monocultures change with future invasions by "secondary invaders" like *Centaurea* and other exotic forbs? (Sheley, D'Antonio, Leger, Germino)
- How effective are state-and-transition models for restoring *Bromus* invaded rangelands, and how well can they transfer among species, regions, and climate scenarios? How can these models be integrated into a resistance and resilience framework? (D'Antonio, Chambers, Pellant, Brown and others)
- What are best and prospective practices for *Bromus* control, including livestock grazing, insect or microbial biocontrol, for controlling *Bromus*, and how well do these practices transfer among species, regions, and climate projections? (Pellant, Hardegree, Pyke, Sheley, Beckstead, Brown)

4) Communication and technology transfer

- What are the most effective modes of communication and technology transfer, and how have these evolved and how might they continue to change? (Brunson, Fernandez-Gimenez and a representative from each program)

<u>B) Development of a database linked to a website to facilitate synthesis-</u> A *Bromus* database will be developed to facilitate research on *Bromus* invasions. A database focused specifically on the genus *Bromus* will allow researchers to quickly locate information on *Bromus* species worldwide and to make comparisons between invasive and non-invasive species. The database will allow interactive queries of historic, current, and future changes in *Bromus* distribution, status, and biological aspects such as reproduction, genetics, and interactions with abiotic environmental factors and with other organisms. The database will also include: 1) descriptions (metadata files) and locations of relevant research and management activities in the region; 2) complete searchable bibliography on the genus *Bromus*; 3) information on individuals (experts) working on *Bromus*, and 4) links to other useful websites. Table 2 includes examples of types of data that will be included.

While other databases contain information about *Bromus* species, many are associated with a specific region of the world. Examples of existing regional databases that contain

information about *Bromus* species are the USDA plants database, the BiolFlor database of plants in Germany and central Europe, and the FloraBase database of Western Australia. Regional databases contain a wealth of information, however, they may not help to identify plants with invasive potential that have not yet been introduced into a specific region. Researchers who are interested in a particular species of plant must try to find and combine diverse types of information from various regional databases, and may find it difficult to make comparisons. Others databases such as GrassBase (Kew Gardens) focus primarily on identification or contain information only about invasive species (the Global Invasive Species Database for example). The *Bromus* database will provide a centralized location and a consistent format for information about this important genus, and will facilitate research about *Bromus* invasions and about factors that contribute to plant invasiveness.

Database development will be led by Cynthia Brown and graduate student Sheryl Atkinson of Colorado State University. They will work interactively with REEnet working groups, which will make recommendations on populating the database and pose questions for synthetic queries for use in symposia presentations, proceedings and development of future research. Database development will be preceded by an assessment of existing databases and their specializations in order to minimize redundancy in our efforts. An early prototype database will be developed and presented to REEnet members at the introductory meeting to be held in Salt Lake City, January 2010. The resulting feedback will be used in the development of the final requirements and design (Fig 3). Additional feedback will be requested from REEnet members during database development, and the database will be made available for testing by REEnet members before the first release.

The *Bromus* database will be a relational database, and will be developed using Microsoft SQL Server Express. A Microsoft Access front-end will be developed for initial data input. A requirements document, a design document, a database schema, and a user's manual will be provided. Web site design and hosting will be provided through existing GBRMP arrangements with the USGS Snake River Field Station through the USFS RMRS. Sean Finn of the USGS has been the lead coordinator of the website. The *Bromus* database user interface will be available on the GBRMP web site.

C) Establishment of an internet chatroom to facilitate interaction- An internet chatroom will be maintained on the *Bromus* REEnet node of the GBRMP website, along with the database described above. The purpose of the chatroom is to foster interaction of core REEnet participants and others who work on *Bromus*. The chatrooms can serve as a means for enabling the subgroups to develop their projects and the resulting presentations and manuscripts efficiently. Notification and information about the chatroom will be made available through the many relevant invasive plant websites and society newsletters.

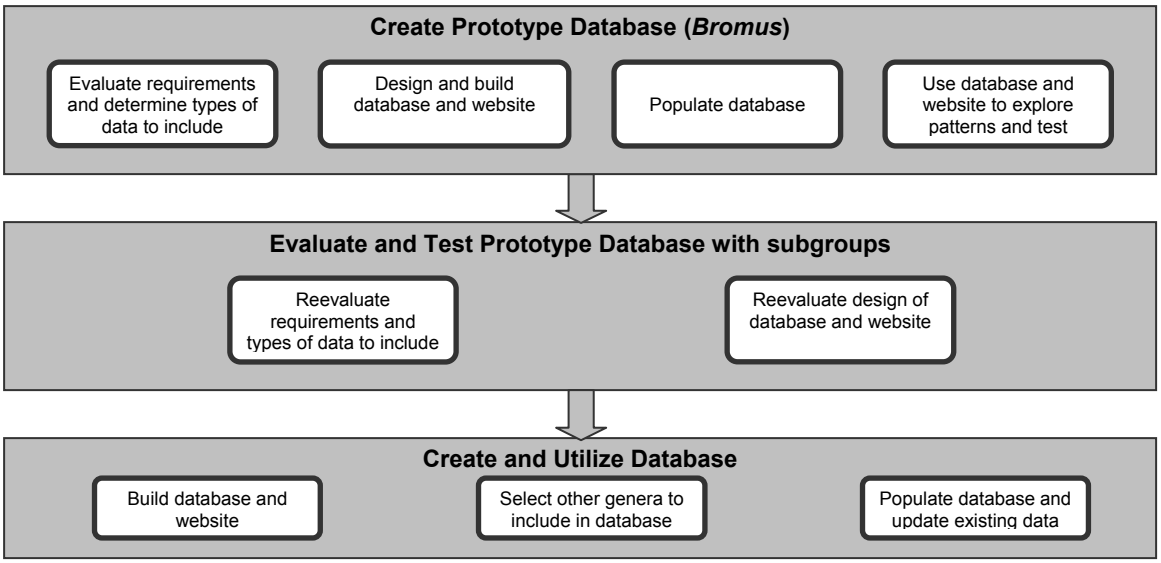

Figure 3. Database development cycle with prototype database (Atkinson and Brown, in press).

Table 2. Examples of types of information to be included in the database.

Information form in database	General Characteristics	Specific Examples
Identification	Taxonomy	Genus, species, tribe
	Other names	Common names
		Older scientific names
Physical features	Height	
	Growth form	
	Identifying features	
Native range	Countries	Abundance
Introduced range	Countries	Naturalized, invasive,
		Introduction pathways
		Introduction dates
		Impact
		Control measures
Biology	Life cycle	Annual, perennial, biennial
Physiology	Phenology	Emergence time, flowering time
	Growth traits	Growth rate, specific leaf area, root to shoot ratio
Reproduction	Asexual reproduction	Rhizomes, stolons, apomixes
	Sexual breeding system	Outcrossing, self-compatible, self-incompatible
	Sexual reproduction	Time to seed, seed mass, number, dispersal, viability, and survival
Genetics	Chromosomes	Haploid chromosome number, ploidy level
	Size of genome	
	Level of genetic diversity	
Habitat preferences	Habitat type	Coastal, riparian, wetlands, grassland, desert,
	Soil	Texture, pH, fertility
	Associated disturbance	Flooding, fire, grazing
	Temperature	Average maximum, average minimum
	Water Availability	Xeric, mesic
Biotic interactions	Herbivores	Insects, ungulates
	Mycorrhizal association	Highly dependent, facultative
	Diseases	Fungal, bacterial, viral
Impacts	Agricultural	Contaminate seed, compete with crops
	Ecological	Alter nutrient cycling, compete with native species
	Economic	Costs for control, reduced yields
References	Publications, data, databases	
Links to other information	Databases, web sites	

D) Proceedings and other publications- We will seek to have a major publisher such as Springer, Island Press, or a major University Publisher publish the proceedings from our second meeting,

which will include a symposium. We also will consider a special volume of a major journal, such as *Ecological Applications, Invasive Plant Science and Management,* or *Biological Invasions*. Where publishers request editorial assistance, we will recommend PIs or other *Bromus* REEnet participants with editorial competence.

We also anticipate submission of review articles, such as a review or synthesis paper led by Matt Brooks on how the current matrix of *Bromus* invasion and land uses might set the stage for movements of other *Bromus* species and development of unique exotic communities under climate change. Possible journals include *American Naturalist,* or *Bioscience*.

E) Involvement of the extension and management community

Extension personnel, land managers and producers will be invited to participate in the second projects described above, which include a symposium and development of white papers. REE-net participants who are extension personnel will translate the scientific findings into presentations and electronic documents appropriate for land managers and producers. These will be made available on the *Bromus* REE-net node of the GBRMP website. Furthermore, programs like the EBIPM have outreach and demonstration projects with landowner groups, USDA NRCS, state extension, and similar stakeholders that provide direct linkages for *Bromus* REEnet to exchange communication and information.

Project evaluation: internal assessments and external peer review:

Results of the *Bromus* REEnet project will be evaluated both internally and externally. The PIs will solicit feedback from all *Bromus* REEnet participants after the first year of the project on their opinions about the structure, effectiveness, and future directions of the *Bromus* REEnet. The PIs will then collate the responses into a short synopsis and allow for discussion and any needed responses by the whole group. Group assessment and feedback are formally built into the database and website design and construction in our project plan. External feedback and evaluation will occur when we discuss and apply to a society for symposia, to a publisher or journal for proceedings dissemination, when we present at symposia, and when we receive reviews to this proposal at the beginning of the project and to the whitepapers and grant proposals that will be an outcome nearer the end of our project. We anticipate that the AFRI BWISA program manager will attend at least the symposia, and we will solicit meaningful feedback about the whole project at that point. As a formal working group of the GBRMP, the *Bromus* REEnet will also benefit from the regular attention, consideration, and feedback of the GBRMP coordinating and executive committees.

***How the products – a network, proceedings, proposals, database, and website - will be use*d:**

The networking proposed here will open lines of communication and idea exchange between the different groups working on *Bromus*, improving inter-awareness of objectives, methods, and outcomes. We anticipate this communication will be used to enhance each existing project, and to pursue new and integrative opportunities. The symposium proceedings will be used to disseminate the outcomes of sub-group projects. The database will be used to synthesize information and make an efficient platform for further *Bromus* inquiries and updating of new information. The website will be used to foster communication on *Bromus* within and outside of the *Bromus* REEnet. Overall, the project outcome will be used to stimulate research and extension on the impacts and control of Brome grasses in rangelands.

Pitfalls that may be encountered and limitations to proposed procedures:

The extent of *Bromus* problems and thus number of research and management programs and personnel working on *Bromus* requires a substantial number of participants for the proposed project. Budget expenditures mainly provide for travel costs, database development, web support and dissemination, and publication costs. The budget will not be able to provide direct compensation to any participant for their time invested into the networking efforts. In the management plan, we discuss key stylistic approaches that will think will sustain the voluntary contributions of participants to the *Bromus* REEnet goals. Other regular challenges that bear some uncertainty are acceptance of symposia proposals, acquiring a contract with a publisher or journal for proceedings, and budget shifts with changes in transportation costs.

Schedule: YEAR:	2009	2010												2011												2012												2013												beyond
MONTH:	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Review AFRI panel assessment & feedback	x																																																	
Preliminary meeting planning	x																																																	
Meeting 1: Introduction and goal setting		x																																																
Subgroups interact, addressing questions		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Website development		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Chatroom establishment & advertisement		x	x																																															
Prototype design of database		x	x	x	x																																													
Regular teleconferences, updates						x				x				x												x				x								x				x								
Evaluation & testing of prototype database						x	x	x																																										
Database development									x	x	x	x	x	x	x	x	x	x																																
PI's canvas participants for internal assessment														x																																				
Symposia and proceeding scoping teleconference																		x			x																													
Inquiries & applications to societies for symposia																						x																												
Seek publisher																							x																											
Receive society & publisher feedback																																																		
Advertise symposia & solicit contributions																								x	x																									
Meeting 2: Symposia (if Ecol Soc Am)																																	x																	
Proceeding chapters submitted																																		x																
External peer review of chapters, revisions																																			x	x	x	x	x	x	x									
Whitepaper & proposal discussions																																													x					
Meeting 3: Whitepaper, proposal development																																																x		
Proposals submitted, reviews received																																																		x
Summary of events by theme:																																																		
Whole-group discussions, in-person &teleconference		x				x				x				x				x			x					x				x			x					x				x			x			x		
Formal feedback on project, internal & external	x					x	x	x						x																					x	x	x	x	x	x	x									x
Milestones: Outputs produced		Website Chatroom																Database															Symposia Presentations								Proceedings								Whitepapers Proposals	